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# Comparison of field and laboratory spectro-directional measurements using a standard artificial target

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## ABSTRACT

Spectro-directional surface measurements can either be performed in the field or within a laboratory setup. Laboratory measurements have the advantage of constant illumination and neglectable atmospheric disturbances. On the other hand, artificial light sources are usually less parallel and less homogeneous than the clear sky solar illumination. To account for these differences and for determining for which targets a replacement of field by laboratory experiments is indeed feasible, a quantitative comparison is a prerequisite. Currently, there exists no systematic comparison of field and laboratory measurements using the same targets.
In this study we concentrate on the difference in spectro-directional field and laboratory data of the same target due to diffuse illumination. The field data were corrected for diffuse illumination following the proposed procedure by Martonchik[1]. Spectro-directional data were obtained with a GER3700 spectroradiometer. In the field, a MFR sun photometer directly observed the total incoming diffuse irradiance. In the laboratory, a 1000W brightness-stabilized quartz tungsten halogen lamp was used. For the first direct comparison of field and laboratory measurements, we used an artificial and inert target with high angular anisotropy. Analysis shows that the diffuse illumination in the field is leading to a higher total reflectance and less pronounced angular anisotropy.

Keywords: BRDF, goniometer, spectrometry, spectro-directional reflectance, diffuse irradiance, artificial target

## 1. INTRODUCTION

The goniometer system of the Remote Sensing Laboratory (RSL) can be used for spectro-directional field measurements (Field Goniometer System FIGOS) and spectro-directional laboratory measurements (Laboratory Goniometer System LAGOS)[2]. However, there are obvious differences between the two cases, which have to be considered:

- In field experiments the target is left in its natural environment and is exposed to the natural direct and diffuse illumination. Diffuse illumination is depending on the illumination zenith angle and the atmospheric conditions. It is present in the field also under clear sky conditions, but is usually neglected in the laboratory.
- The direct illumination by the sun can be treated as being parallel (within 0.5°) and homogeneous over the area and height profile of the target, while laboratory illumination is usually non-parallel, non-homogeneous and not constant as a function of the target height.
- The illuminated area in the laboratory is limited; adjacency and multiple scattering effects can therefore be very different to field experiments.
- The spectrum of artificial light sources differs from that of the sun, which is additionally attenuated by the atmosphere. This is usually neglected since reflectance measurements are normalized using a reference target.

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- The polarization of the natural and artificial light sources can be different.
- Living plants may behave differently under field and laboratory conditions.

Taking these differences into account, the advantage of laboratory measurements lies in the independence of weather conditions, time of day or seasonal conditions. The illumination intensity and angles can be held constant over time and freely chosen.
Currently, there exist no systematic comparisons of field and laboratory measurements using the same artificial targets and therefore it is not known for which targets a replacement of field by laboratory measurements is indeed feasible. This study has been performed focusing on the effects of the diffuse illumination as the main difference between spectro-directional field and laboratory measurements.
The directional surface reflectance properties are by definition characterized by the bidirectional reflectance distribution function (BRDF), or equivalently, the bidirectional reflectance factor (BRF) and depend on the surface properties only.[3] However, spectro-directional field experiments with goniometer systems are only able to observe approximations of the bidirectional reflectance factor. The directly observed quantity in field experiments is called hemispherical conical reflectance factor (HCRF), corresponding to hemispherical illumination, which depends on the atmospheric conditions, and conical observation. Laboratory experiments suffer from imperfect illumination resulting in a rather biconical than bidirectional reflectance factor. In this preliminary study the conicality on the illumination and observation side has been neglected. This is acceptable for the observation side since the field of view (FOV) of the sensor is quite small (3°). Current studies at RSL pay attention to the conicality of both the illumination source and the sensor. Additionally, the changing size and position of the sensor's footprint as a function of the observation angle have to be considered, especially if the target is not very large or exhibits different BRDF's at different parts.
In order to make measurement results of field and laboratory spectro-directional experiments directly comparable, we need to retrieve the BRDF for both cases. For the field case we followed the well known procedures proposed by Martonchik and others[1 4], which correct the measurements only for the diffuse illumination and not for any other imperfections. For these methods, the diffuse radiation has to be measured over the complete hemisphere at the same angular resolution as the reflected radiation of the target. Since we are not yet able to measure the incoming diffuse radiation at angular resolution, we used a simplified approach measuring the diffuse irradiance with a MFR sun photometer. For the laboratory case, the approximated BRF is used since the standard retrieval schemes do not apply because they rely on the separation of direct and diffuse illumination.

## 2. METHODOLOGY

### 2.1 Comparison requirements

For comparison purposes of spectro-directional field and laboratory measurements it is necessary to hold as many parameters as possible constant. So, the target, the measurement instruments, the experiment setup, the illumination and observation geometries, directions and areas remain the same. As mentioned, a basic difference of the two measurement cases is that in the laboratory we obtain BRF data and in the field HDRF data, using the approximations discussed above. Field data is influenced by atmospheric conditions, especially by the diffuse irradiance, which has to be corrected. For spectral analysis we compare the averaged nadir reflectances from 400 to 2500 nm. Directional analysis is mainly done in the solar principle plane at a wavelength of 496 nm.

- **A) Target:** For the first direct comparison of spectro-directional field and laboratory measurements we used an artificial, inert target, borrowed from JRC[5] (Fig.1). The target size is 25 cm x 25 cm and it consists of a matrix of cubes, carved out of a thick plate of sanded duralumin. The spectro-directional properties show a high angular anisotropy due to the cast shadows of the cubes as a function of the illumination angles.Furthermore, its

BRDF is not rotationally symmetric (only 90° symmetry), it depends on the illumination and view azimuth angles. In order to reduce adjacency effects due to the limited size of the target, a black aluminum plate (size 1.2 m x 1.2 m) was used as background in both the laboratory and field case.

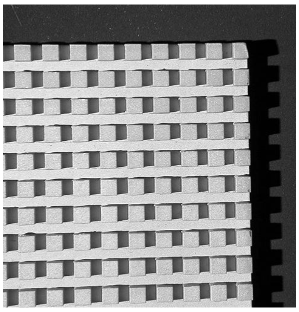

Fig. 1: Anisotropic target.

- **B) Instruments and experiment setup:** The field and laboratory experiments were performed using the same measurement setup: a GER3700 sensor, mounted on the goniometer system, measuring the spectro-directional reflectances over the whole hemisphere at an azimuthal angular resolution of 30° and a zenithal angular resolution of 15°. For a detailed description of RSL's goniometer system please refer to Sandmeier et al.[6]. In the field case, additionally, the total and diffuse illumination is permanently measured with a MFR-7 sun photometer (Yankee Environmental Systems Inc.) at 6 wavelengths (415, 500, 615, 673, 870, and 940 nm). The direct illumination is then obtained computing the difference between the total and diffuse illumination. In the laboratory case, a 1000W brightness-stabilized quartz tungsten halogen lamp was used as illumination source[2]. The lamp is mounted on an adjustable tripod, which allows the use of the same illumination directions of the target as in the field case.
- **C) Illuminated area:** The illumination distance (distance from the light source to the centre of the target) in the laboratory was held constant at 1.54 m for all illumination angles. For the smallest used illumination angle (28.5°) the illumination ellipse shows a size of about a = 32.25 cm (short half axis) and about b = 37 cm (semi-major axis). However, for larger illumination zenith angles the semi-major axis is changing, which leads to an increase of the inhomogeneity and non-parallelism over the illuminated area. These effects were neglected in this study since the illumination distance remains the same and those effects particularly appear in the forward direction and at a great distance from the central part of the beam.
- **D) Observed area:** Similar effects of a changing instantaneous ground field of view (IGFOV) also occur on the observation side. In order to reduce adjacency effects we concentrated on observation angles from +45° to -45° in the analysis of the data.

### 2.2 Correction for diffuse irradiance

There are various methods to assess the diffuse illumination in HDRF measurements[1 4 7]. In this study we followed the procedure from Martonchik[1], where the incidence irradiance is split up into a direct and diffuse component $E_{dir}^{inc}(\mu_0)$ and $E_{diff}^{inc}(\mu_0)$. The diffuse influence then is accounted for in a correction term which is subtracted from the reflected field radiances $L(\mu, \mu_0, \varphi, \varphi_0)$. The resulting $BRF_\Delta$ then is

$$BRF_\Delta = \frac{L(\mu, \mu_0, \varphi, \varphi_0) - \Delta(\mu, \mu_0, \varphi, \varphi_0)}{\pi^{-1}[E_{dir}^{inc}(\mu_0) + E_{diff}^{inc}(\mu_0)]}, \tag{1}$$

where

$\mu, \mu_0$ is the cosine of the view and illumination zenith angle and

$\varphi, \varphi_0$ is the view and illumination azimuth angle.

$E_{dir}^{inc}(\mu_0)$ and $E_{diff}^{inc}(\mu_0)$ are measured by the MFR and the diffuse influence is described by

$$\Delta(\mu,\mu_0,\varphi,\varphi_0) = \pi^{-1}\int_0^1\int_0^{2\pi} R(\mu,\mu',\varphi,\varphi')L_{diff}^{inc}(\mu',\mu_0,\varphi',\varphi_0)d\Omega - \pi^{-1}R(\mu,\mu_0,\varphi,\varphi_0)\int_0^1\int_0^{2\pi} L_{diff}^{inc}(\mu',\mu_0,\varphi',\varphi_0)d\Omega\,, \quad (2)$$

where

| | |
|---|---|
| R | is the BRF of the target, |
| $L_{diff}^{inc}(\mu',\mu_0,\varphi',\varphi_0)$ | is the diffuse incident radiance [$Wm^{-2}sr^{-1}$] and |
| $d\Omega$ | is $\mu' d\mu' d\varphi'$, the projected solid angle. |

In our case we assume that $L_{diff}^{inc}$ is constant over the angles (since the MFR only observes the total incoming diffuse irradiance), and therefore the integral $\int_0^1\int_0^{2\pi} L_{diff}^{inc}(\mu',\mu_0,\varphi',\varphi_0)d\Omega$ becomes the constant factor $E_{diff}^{inc}(\mu_0)$:

$$\Delta \cong \pi^{-1}E_{diff}^{inc}(\mu_0)(\pi^{-1}\int_0^1\int_0^{2\pi} R(\mu,\mu',\varphi,\varphi')d\Omega - R(\mu,\mu_0,\varphi,\varphi_0))\,, \quad (3)$$

The $\Delta$ term in equation (3) is a function of the diffuse irradiance and the target anisotropy. The anisotropy is determined using the difference of the target BRF and the BRF integrated for a specific illumination angle.
Normalizing field measurements with the total diffuse irradiance (instead of the spectralon reference), additionally provides the possibility to correct for a non perfect lambertian behaviour of the spectralon reference due to abrasion and for the changing atmospheric conditions during the time it takes to measure a hemisphere (spectralon reference is only taken at nadir positions, sun photometer data is available at time intervals of 30s). A spectralon correction factor k can then be computed using the ratio

$$k = \frac{HDRF_{(mfr)}}{HDRF_{(spec)}}\,. \quad (4)$$

## 3. DATA

The field data for this study has been acquired in July 2002 at the airport Oberpfaffenhofen in Gilching (D). With FIGOS, a total of 6 hemispheres of the artificial JRC target were measured at different illumination angles. The MFR sun photometer was recording direct and diffuse irradiance data permanently from 11:48h until 18:30h. During the measurement day, the illumination of the sun changed by 153.4° in azimuth and 31.8° in zenith direction and reached its highest position at a zenith angle of 27.4° at 13:21h. Meteorological conditions were favourable with a sky cover of 1/8 until 14:00h but changed to a broken cloudiness at about 6000 ft base level in the late afternoon.
For LAGOS, 6 hemispheres under the same illumination angles as in the field have been measured in the goniometer laboratory at RSL. Fig. 2 shows an overview of the comparable spectro-directional dataset with illumination zenith angles zn and azimuth angles az with respect to the target grid:

| Hemisphere | mean zenith [°] | mean azimuth [°] |
|---|---|---|
| Hem/Labhem_b | 37.8 | 5.4 |
| Hem/Labhem_c | 33.3 | 17.6 |
| Hem/Labhem_d | 28.7 | 42.2 |
| Hem/Labhem_f | 28.5 | 11.5 |
| Hem/Labhem_i | 40 | 29.5 |
| Hem/Labhem_j | 59.4 | 32.6 |

Fig. 2: Spectro-directional dataset

### 3.1 Quality assessment

To fulfil the comparison requirements described in 2.1., only spectro-directional reflectance data from +45° to -45° zenith angle for both LAGOS and FIGOS are considered for analysis. Due to shadowing of either the sensor (field) or the lamp (laboratory), no measurement near the hotspot is possible. In the laboratory, even measurements in the principal plane at zenith angles larger than the actual illumination zenith angle are affected by shadowing of the tripod in the backscattering region and have to be omitted.

In order to compare field and laboratory measurements with respect to the changing influence of the diffuse illumination, spectro-directional data at different times of the day were obtained. In the following, we consider the diffuse irradiance at 496 nm. Fig. 3 shows the ratio of the diffuse irradiance to the direct irradiance, along with the measuring times of the hemispheres c, d, f, i and j.

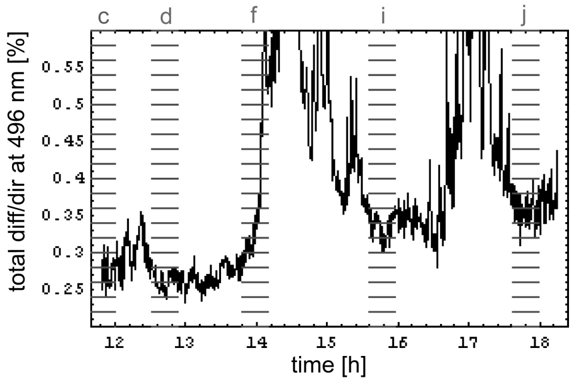


Fig. 3: Diffuse quantity at measurement times.

The diffuse influence is increasing with the illumination zenith angle, but also depending on the sky cover (overpassing clouds at 14h-15h and 17h). The hemispheres f and j underlie a strong diffuse influence and therefore a strong discrepancy to the corresponding laboratory measurements is expected.

To merge the spectro-directional field data with the irradiance data, as described in 2.2., the GER3700 data have been convoluted to a bandwidth of 10 nm in order to match the MFR bandwidth.

## 4. RESULTS

### 4.1 Spectral and directional results

Generally, the nadir reflectance over the whole spectrum (400 nm to 2500 nm) is decreasing with an increasing illumination zenith angle. Maximal reflectance in the dataset is measured for zn=28.7° (Hem/Labhem_d) and minimal reflectance for zn=59.4° (Hem/Labhem_j), resulting from the increasing cast shadow of the target cubes at larger illumination zenith angles. Nadir reflectances of FIGOS show higher values than of LAGOS, but the differences depend on the illumination zenith angle (Fig. 4):

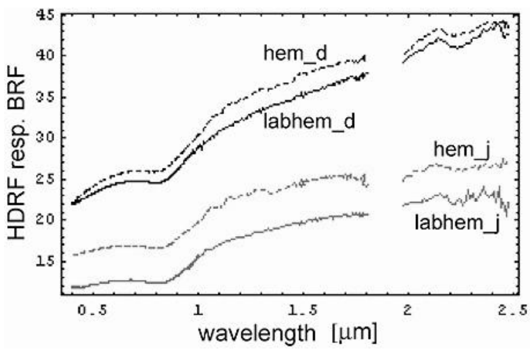


Fig 4: Reflectance difference for zn=59.4° (Hem/Labhem_j) and zn=28.7° (Hem/Labhem_d).

A larger illumination zenith results in a longer path of the solar radiation through the atmosphere and therefore in more diffuse light which is illuminating the strong cast shadows of the cubes of the JRC target. Imagine yourself looking at the target from the nadir position: the shadowed area will grow with increasing illumination zenith. And therefore, more dark (shadowed) area is available to be illuminated by the diffuse irradiance in the field, but not in the laboratory.

Directional analysis is done for a wavelength of 496 nm. Directional reflectance effects are very distinctive in the solar principle plane reaching a maximum reflectance of 25% – 30% in the forward scattering region for both laboratory and field measurements. Dominant structures of the reflectance distribution are pronounced in BRF data whereas in HDRF data a levelling of these structures is observed (Fig. 5). This levelling occurs due to the diffuse irradiance illuminating shadowed areas behind the target cubes. The reflectance difference between a bright (direct illuminated) and a dark (shadowed area in the laboratory, but diffuse illuminated area in the field) area is bigger in BRF data than in HDRF data.

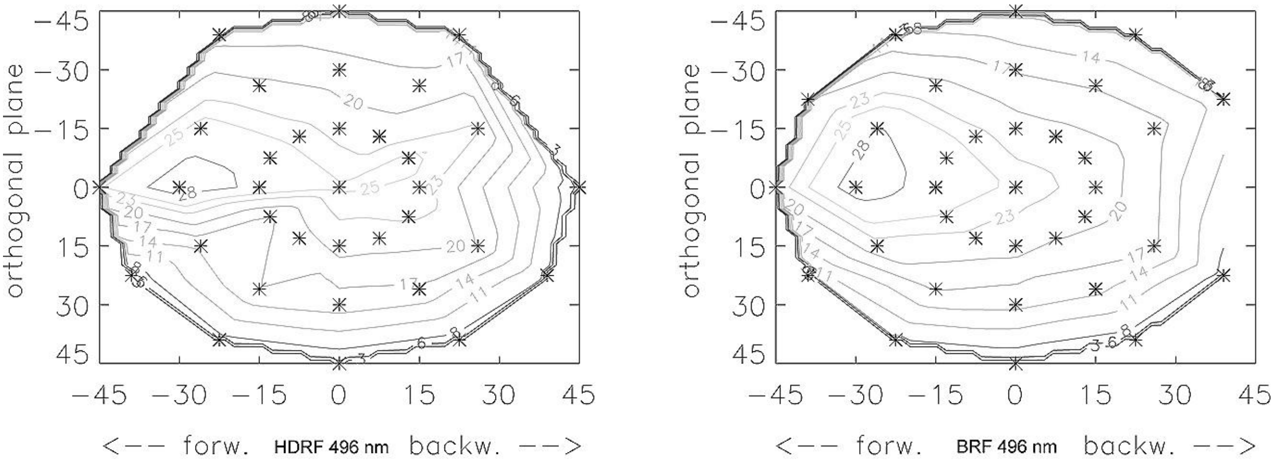


Fig 5: Levelling effects of dominant reflectance structures due to diffuse irradiance in field measurements (Hem/Labhem_f).

### 4.2 Correction results

A comparison of the mean reflectances of the corrected $BRF_{\Delta}$ data to the original field and laboratory data reveals, that for large illumination zenith angles the correction is better than for small illumination zenith angles. However, the significance of the mean reflectance is minor, since only zenith angles from +45° to -45° are considered. The correction quality is therefore mainly discussed in the solar principal plane. The correction term is not useful for atmospherically little influenced hemispheres, since the diffuse influence is small and the correction method is not very sensitive.

But the $BRF_{\Delta}$ of hem_j, which is strongly influenced by diffuse irradiance, exhibits a very good correction as shown in Fig. 6:

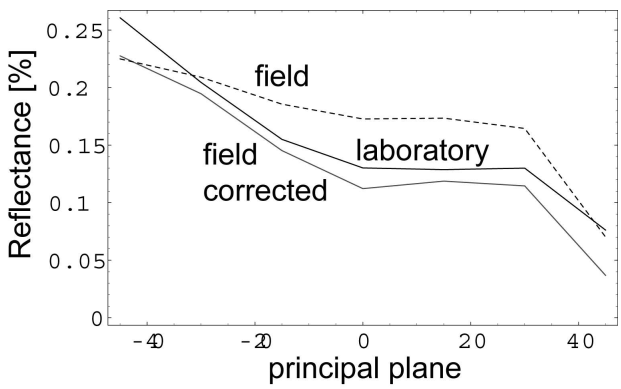


Fig 6: Hem_j corrected for diffuse irradiance

However, for hem_f (also strongly influenced by diffuse irradiance) the correction term fails. An explanation might be, that the diffuse irradiance here is caused by moving clouds, instead of a large illumination zenith angle as for hem_j. This might lead to an inhomogeneous diffuse irradiance, which is not accounted for with our approximation for equation (3) ( $L_{diff}^{inc}$ homogenous) for the incident diffuse radiance. A comparison of the original hem_f (spectralon normalized) with the same data but normalized with the total irradiance at the corresponding measurement time, clearly shows the effect of the changing atmosphere. A non changing atmosphere should result in about the same reflectance at different nadir observations (inner circle in Fig. 7), which is not the case for the original hem_f (Fig. 7a):

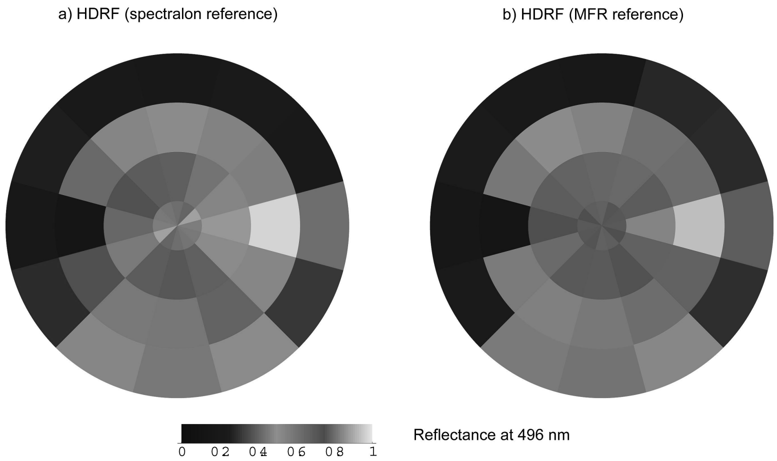


Fig 7: Spectralon reference against MFR reference.

By comparing only single nadir measurements of both reference methods to each other, a spectralon correction factor can be calculated. For the used spectralon panel a degradation of about 23% was determined for a wavelength of 413 nm and about 6% for a wavelength of 671 nm within the last 5 years. This effect leads to higher than real reflectance values in spectralon normalized data.

## 5. CONCLUSIONS

In this study a direct comparison of spectro-directional field and laboratory measurements using an artificial target has been performed for the first time. We concentrated on the difference due to the diffuse illumination and applied a correction method following the well known approach by Martonchik[1]. For the comparison, an inert (no variation over time) and highly anisotropic (large $\Delta$, since stronger directional effects due to diffuse light), artificial target was chosen. The conclusions of the obtained results are depicted as follows:

- The spectral analysis shows a typically about 2% higher reflectance in field measurements than in the laboratory. This difference increases with increasing illumination zenith angle and occurs due to illumination of shadowed areas in the field case.
- The diffuse irradiance in field measurements leads to a levelling of dominant structures. Maximal reflectance values of about 25% to 30% were obtained in the forward scattering region at an illumination zenith angle of 30° or larger.
- An assessment of the correction method seems difficult, since it is not sensitive enough for field measurements underlying only little diffuse influence. However, for field measurements with large illumination zenith angles good results were obtained. Obviously the angular distribution of the diffuse irradiance may differ depending on its origin, either caused by a long solar radiation path or by a changing atmosphere (sky cover).
- The determined spectralon correction factor revealed a degradation of 6% to 23% of the spectralon reference within about 5 years. Regular calibration is therefore recommended here.

For future investigations concerning the influence of diffuse irradiance in spectro-directional field measurements a large dataset with varying atmospheric conditions is necessary. Better correction can be obtained by measuring the incoming diffuse radiation at the same angular resolution and time as the spectro-directional reflectance. Therefore a goniometer system with two spectroradiometers, one looking upwards and one looking downwards, is proposed[8].
For this comparison study approximations concerning illumination and observation geometries and areas have been made for the laboratory case. Further research is currently done at RSL to account for the non-parallelism of the illumination and inhomogeneity of the illuminated area[9]. In consequence, a larger artificial target of the same characteristics has been produced in order to reduce adjacency effects at large observation zenith angles.

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